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STABILIZATION OF A LIQUID-FILLED SHELL BY INSERTING A CYLINDRICAL PARTITION IN THE LIQUID CAVITY

by

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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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JTFrasier/WPD'Amico/so
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March 1969

STABILIZATION OF A LIQUID-FILLED SHELL BY INSERTING
A CYLINDRICAL PARTITION IN THE LIQUID CAVITY

ABSTRACT

In July 1968, the XM613, a 107mm, WP mortar shell, was range tested at Yuma Proving Ground. The projectile had a history of flight instabilities when the WP was in the liquid state. Specially modified rounds incorporating a cylindrical partition mounted concentrically to the central burster experienced stable flights. The rationale for inserting cylindrical partitions in liquid-filled shell is explained as being a straightforward and flexible method of changing internal geometries to produce stable flight by means of well-founded design procedures.

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I. INTRODUCTION

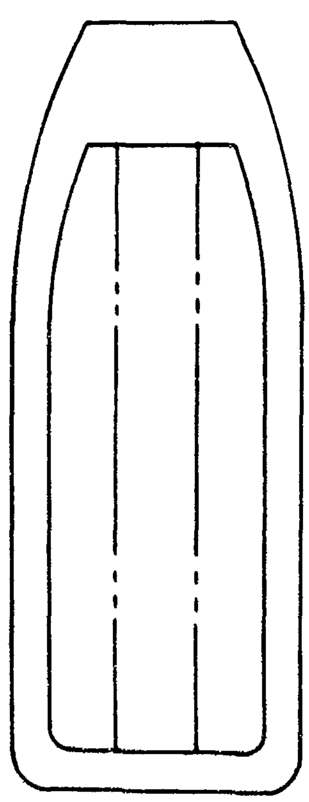
Once castings for a liquid-carrying projectile are made, it is not an easy task to modify the round for the elimination of shell-liquid resonances. Several "ad hoc" approaches for stabilization, longitudinal baffles being the most common, are frequently not successful. It is desirable to establish techniques that make possible "a priori" design control. A concept satisfying this criterion involves the insertion of a cylindrical partition in the payload cavity.

Firings held in July 1968 at Yuma Proving Ground were part of a project termination that included the expenditure of available hardware. Since the XM613 had a history of flight instabilities, blamed upon shell-liquid resonances, this afforded the design engineers a test vehicle for "ad hoc" stabilization methods. At the invitation of personnel from the Artillery and Mortar Section of Picatinny Arsenal and the Weapons Development and Engineering Laboratory of Edgewood Arsenal, the BRL suggested the use of a cylindrical partition. Other modifications made by the MUCOM agencies included the insertion of several types of longitudinal baffles, the use of a gel filler representing thickened WP, and the addition of a sponge material into the shell cavity in an attempt to suspend the WP, i.e., reduce fluid movement. Firings were made from a single tube for a single charge and elevation. Thirty projectiles were thermally cured to a surface temperature of 145°F for a period of twenty-four hours. Four to five rounds were removed from the conditioning oven and fired within thirty minutes until all ammunition was expended. This insured that the filler was in a liquid state. Of the thirty rounds fired only the two rounds that employed cylindrical partitions flew well. These two rounds fell ten meters apart at 6,000 meters. The rationale and design for inserting a cylindrical partition is explained in the following sections.

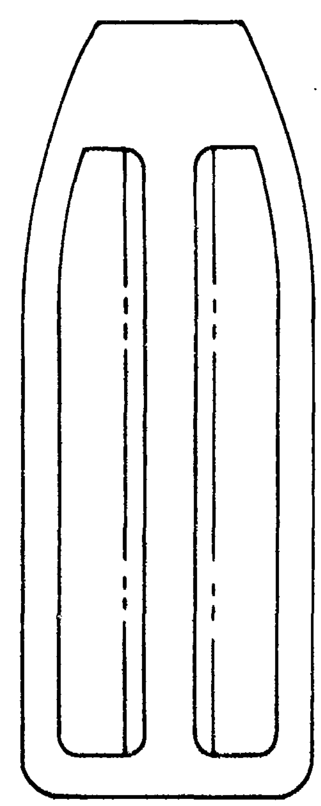
II. TECHNIQUE

Flight instabilities due to liquid payloads are a consequence of resonance between liquid eigenfrequencies and the shell nutational frequency. This matching can occur during liquid spin-up or at a full spin condition. To alleviate such a resonant condition, the shell geometry, the percent of fill, or the shell nutational frequency must be changed. Normally, the liquid payload cannot be significantly altered. A redistribution of mass could shift the shell nutational frequency, but this results in a complete aerodynamic redesign. It appears that a variation in cavity geometry is the best route. This geometry modification should not be a haphazard one.

An intelligent change in geometry can be made by using a cylindrical partition. To illustrate this method, consider the two common shell cavities shown in Figure 1.



1a



1b

Figure 1a and 1b. Typical Shell Cavities

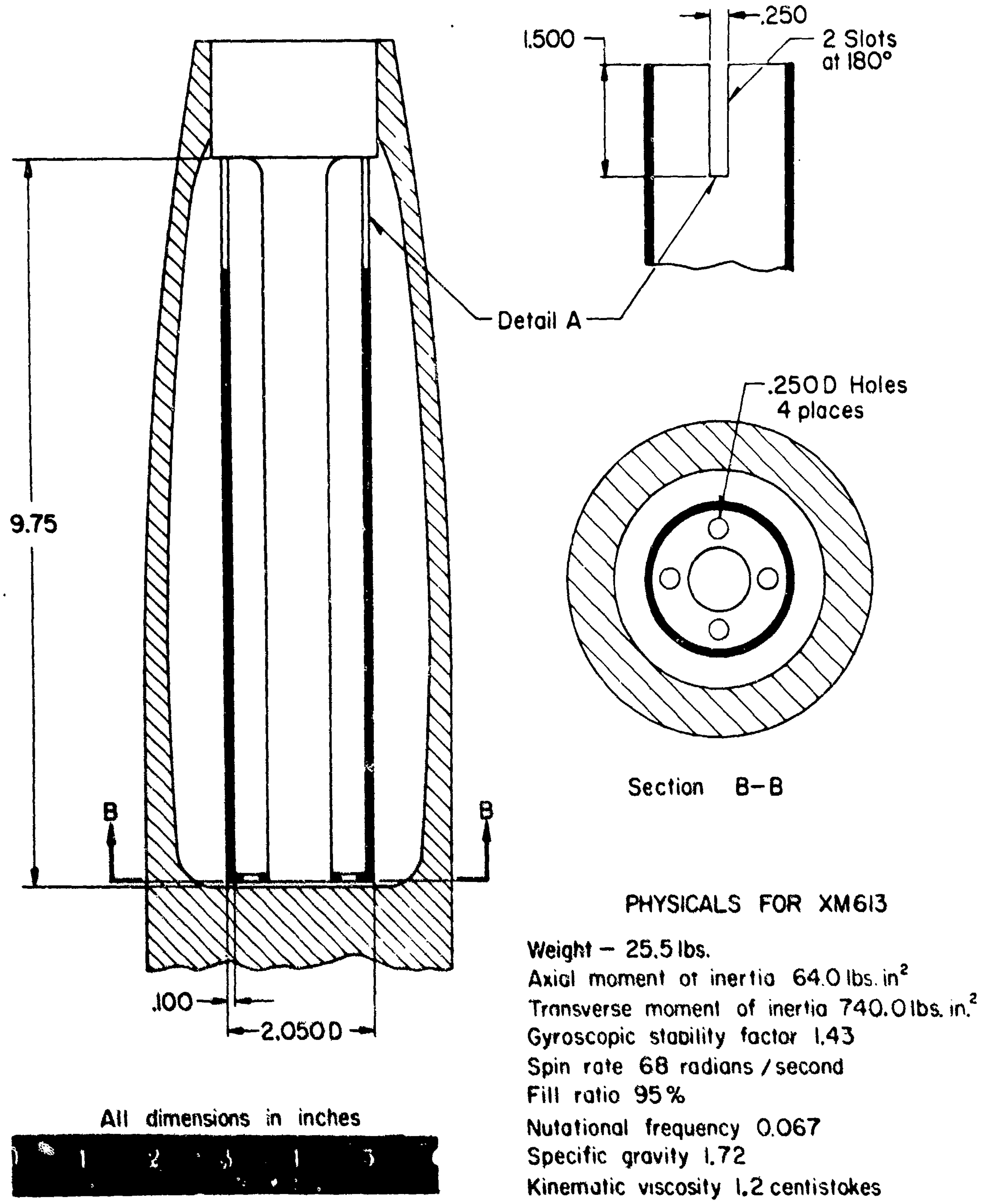
Non-cylindrical cavities are shown with a burster located in the nose and with a central burster. Assume a fill ratio of 95%. A cylindrical partition could be mounted about the longitudinal center line, as indicated by the broken lines. These cylinders are fastened in such a way as to allow the liquid to move over the cylinder edges when it is thrown outward by centrifugal forces. The partition used in XM613 is shown in Figure 2. Since the spinning liquid will seek the outermost position, the outer cavity will be 100% filled after the liquid spin-up process is completed.

III. THEORY AND DESIGN ANALYSIS

Effectively two cavities result from the insertion of a cylinder in a shell cavity. For Figure 1a, the outer cavity takes up boundary conditions of a non-cylindrical wall and a rigid core (100% full). The inner cavity is the well known case treated by Stewartson, consisting of a partially filled cylindrical cavity[1]*. A similar double cavity results in Figure 1b, except that the central burster may act as a rigid core or as a partially wetted rod[2]. If the percent fill is not high enough to cause liquid-burster interference, then both Figure 1a and 1b have the same boundary conditions. Usually a cylinder radius can be selected by means of available theory that will result in a stable flight.[2,3,4]

Assume that an analysis of some non-cylindrical cavity reveals a resonant condition. In the case of the XM613, an unstable flight was caused by a transient resonance. How could a cylindrical partition be selected to stabilize the projectile? For the XM613 geometry shown in Figure 2, it is possible to generate a table of nutational frequencies and rigid core radii that produce resonant conditions for the outer cavity.[3,4] This is done for rigid core, full spin modes. Considering only the first radial mode, Table I lists the longitudinal modes (j = 2, 3, 4, and 5) for a fill ratio of 100% over a range of frequencies close to the XM613 nutational frequency of 0.067.

*References are found on page 14.



PHYSICALS FOR XM613

Weight – 25.5 lbs.
Axial moment of inertia 64.0 lbs. in^2
Transverse moment of inertia 740.0 lbs. in.^{2}
Gyroscopic stability factor 1.43
Spin rate 68 radians / second
Fill ratio 95%
Nutational frequency 0.067
Specific gravity 1.72
Kinematic viscosity 1.2 centistokes

Figure 2. Geometry and Physical Characteristics for the XM613

Table I

τ	$d_{j=2}$ inches	$d_{j=3}$ inches	$d_{j=4}$ inches	$d_{j=5}$ inches
0.00	0.568	0.891	1.036	1.138
0.02	0.616	0.910	1.052	1.156
0.04	0.653	0.927	1.066	1.166
0.06	0.686	0.944	1.081	1.179
0.08	0.718	0.961	1.096	1.194
0.10	0.745	0.978	1.111	1.208

A graphical representation of Table I is shown in Figure 3. The selection of a nonresonant cylinder radius, d, can easily be made. Logical choices would be 0.85" or 1.025". If values of 0.70" or 0.95" were selected, a resonant condition is produced. Once d is chosen then the geometry of the inner cavity is fixed. For the XM613, the cylinder outside radius was made 1.025". The slenderness ratio (height/diameter) of the inner cavity for the j=0 mode was 5.27. The resulting percent of fill for the inner cavity was 62.5%.

The new design must now be checked for viscous effects and transient resonances[5,8]. Conditions for the XM613 were such that no viscous corrections needed to be made. Transient resonances can occur in either of the cavities. Transient eigenfrequencies cannot be explicitly calculated, but the yaw growth while passing through a transient instability can be approximated by the following equation[5,7].

$$\log\left(\frac{\alpha_1}{\alpha_0}\right) = -\left(\frac{\pi\Omega}{4}\right)\frac{S}{d\tau_0/dt} \quad .$$

α_0 = Yaw angle before transient resonance

α_1 = Yaw angle after transient resonance

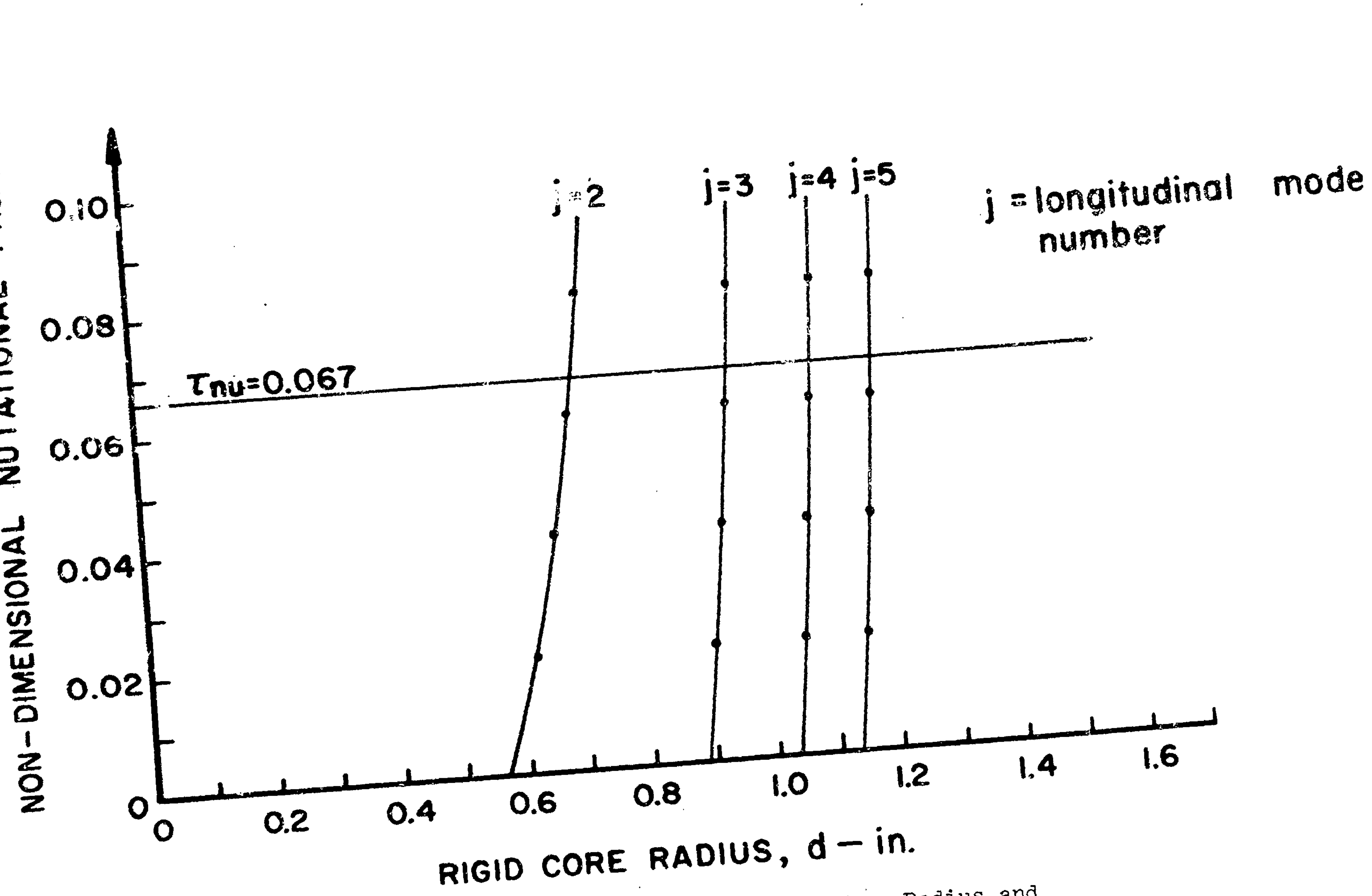


Figure 3. Graphical Representation of Rigid Core Radius and Non-Dimensional Nutational Frequency for the XM613

Ω = Shell spin rate

S = Stewartson's parameter

τ_o = Time dependent, non-dimensional eigenfrequency

t = Time

If $d\tau_o/dt$ is computed correctly, viscous effects in the spin-up process are taken into account. Assumptions made to extend the above equation to partially filled cylinders or to non-cylindrical, solid core cavities are not overly restrictive. For the inner cavity of the XM613, a transient resonance was located for an effective percent fill of 0.597[8]. Since α_1/α_0 was calculated to be 1.35, no serious problems were expected.

IV. SUMMARY

It is quite possible the cylinder radii available from plots such as Figure 2 could still yield serious resonances for either spin-up or full spin conditions. It might then be possible to use more than one cylinder, especially in some of the larger rounds. A multi-cylinder design should still allow for fluid movement, while not decreasing the payload capacity or impairing the manufacturing process. The insertion of a cylindrical partition is most certainly not a panacea. It can be done only with a working knowledge of the references that are cited. A cylindrical partition, however, is at this time the only well-founded method for stabilization of a projectile without cumbersome and expensive alterations.

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13. ABSTRACT

In July 1968, the XM613, a 107mm, WP mortar shell, was range tested at Yuma Proving Ground. The projectile had a history of flight instabilities when the WP was in the liquid state. Specially modified rounds incorporating a cylindrical partition mounted concentrically to the central burster experienced stable flights. The rationale of inserting cylindrical partitions in liquid-filled shell is explained as being a straightforward and flexible method of changing internal geometries to produce stable flight by means of understood design procedures.

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